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(54) **DUAL-POLARIZED OPTICALLY CONTROLLED MICROWAVE ANTENNA**

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(73) Assignee: **Sony Corporation**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 398 days.

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(51) **Int. Cl.**

H01Q 19/06	(2006.01)
H01Q 3/26	(2006.01)
H01Q 15/00	(2006.01)

(52) **U.S. Cl.**

CPC ***H01Q 3/2676*** (2013.01); ***H01Q 15/002*** (2013.01)

(58) **Field of Classification Search**

CPC H01Q 15/002; H01Q 3/2676

USPC 343/754, 753, 755, 772, 776, 786

See application file for complete search history.

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Primary Examiner — Hoanganh Le

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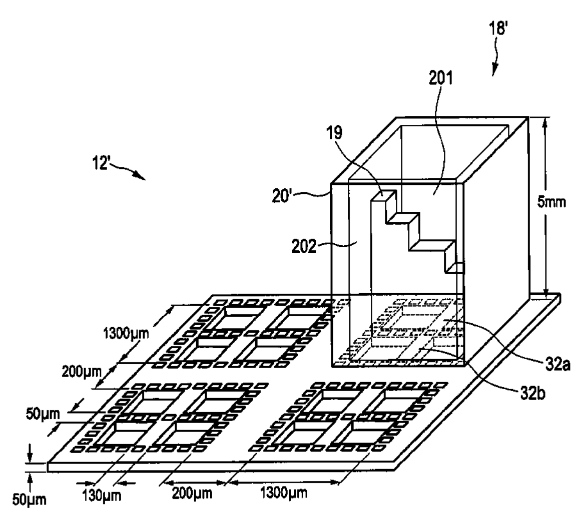
(57) **ABSTRACT**

An optically controlled microwave antenna that reduces the optical power consumed by the antenna and to enable polarimetric detection an optically controlled microwave antenna comprises an antenna array and a feed for illuminating said antenna array with and/or receiving microwave radiation. The antenna array comprises a plurality of antenna elements each including a waveguide, two optically controllable semiconductor elements arranged within the waveguide in front of the light transmissive portion of the second end portion, a controllable light source arranged at or close to the light transmissive portion of the second end portion for projecting a controlled light beam onto said semiconductor element for controlling its material properties, and a septum arranged within the waveguide in front of the light transmissive portion of the second end portion and separating said waveguide into two waveguide portions.

26 Claims, 13 Drawing Sheets



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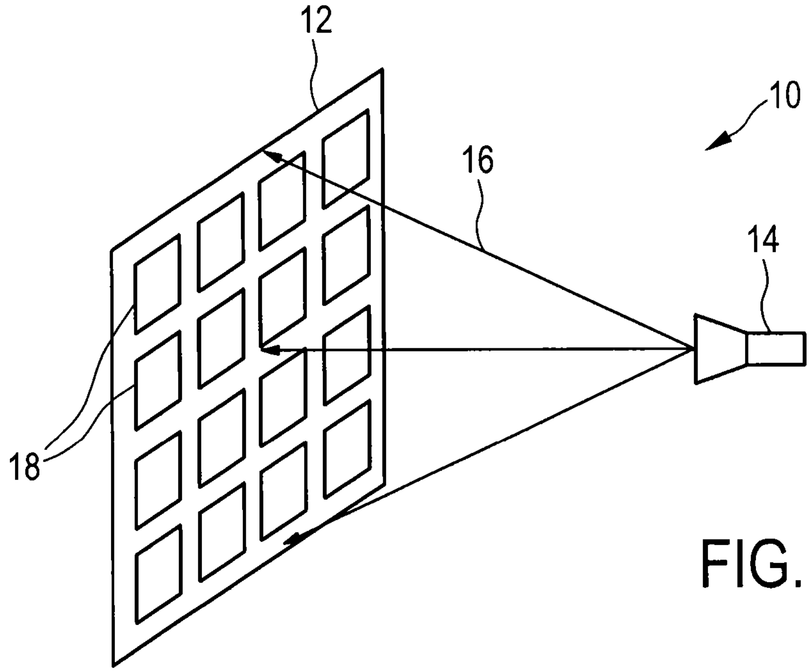

FIG. 1

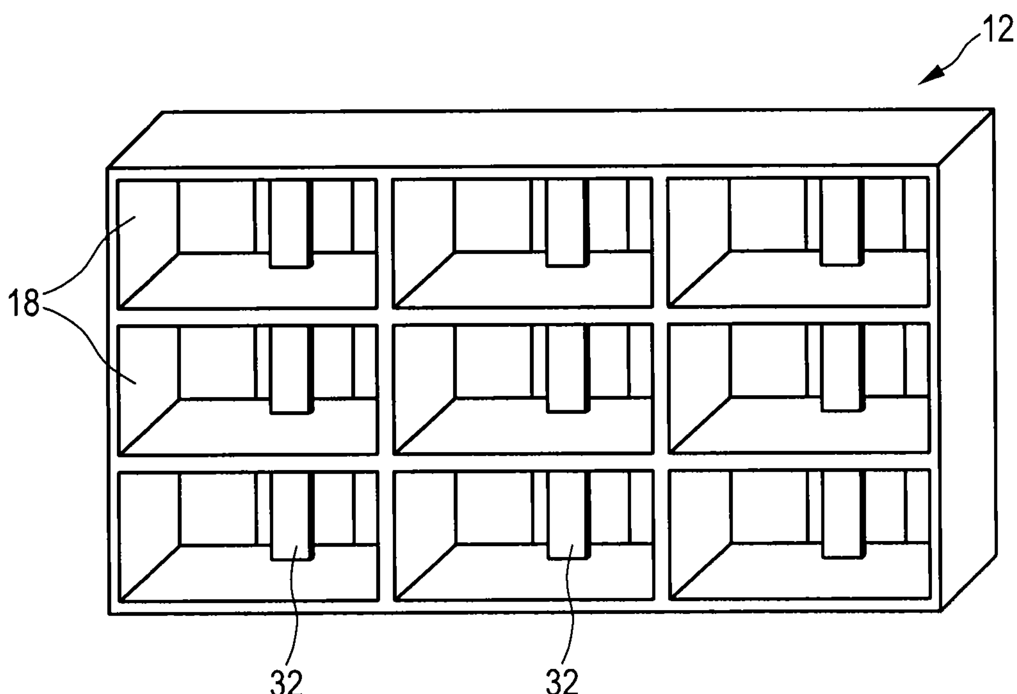

FIG. 2

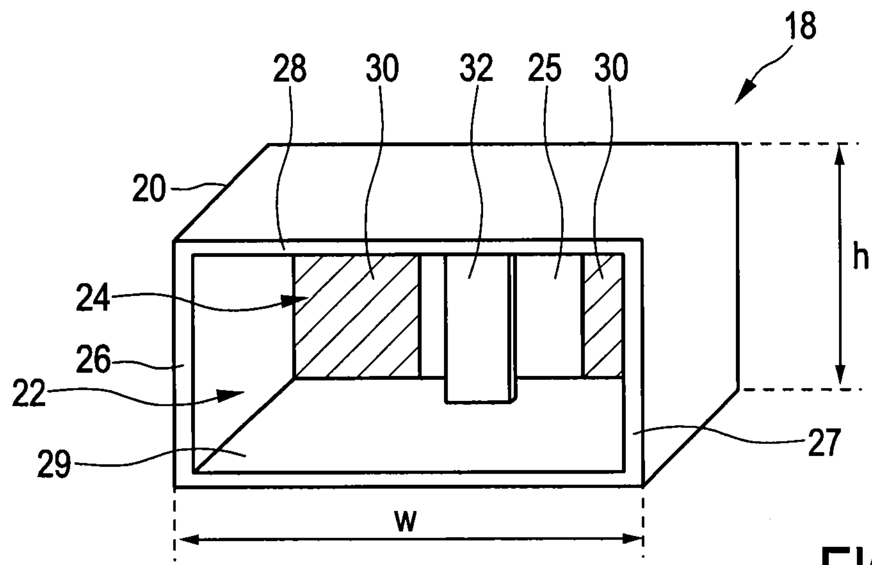

FIG. 3

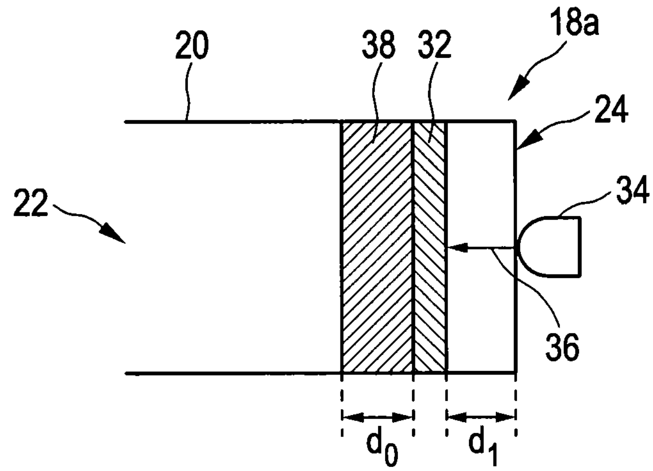

FIG. 4

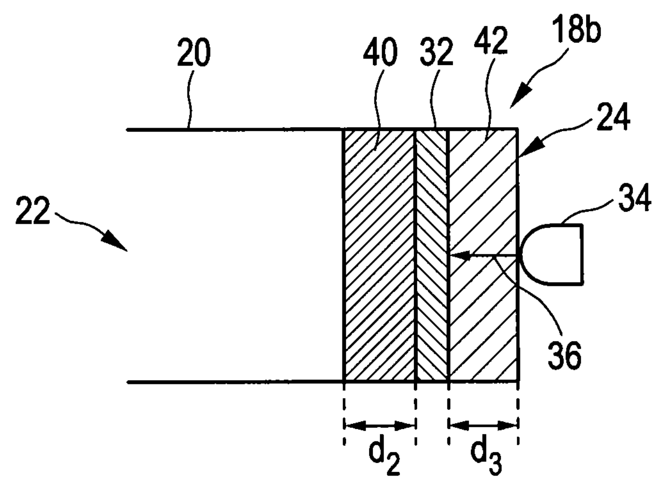

FIG. 5

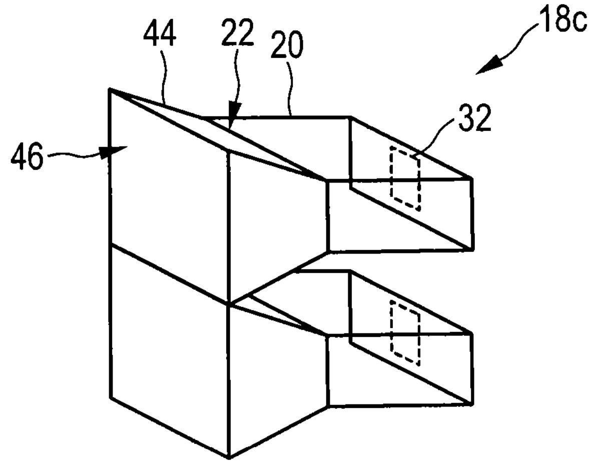

FIG. 6

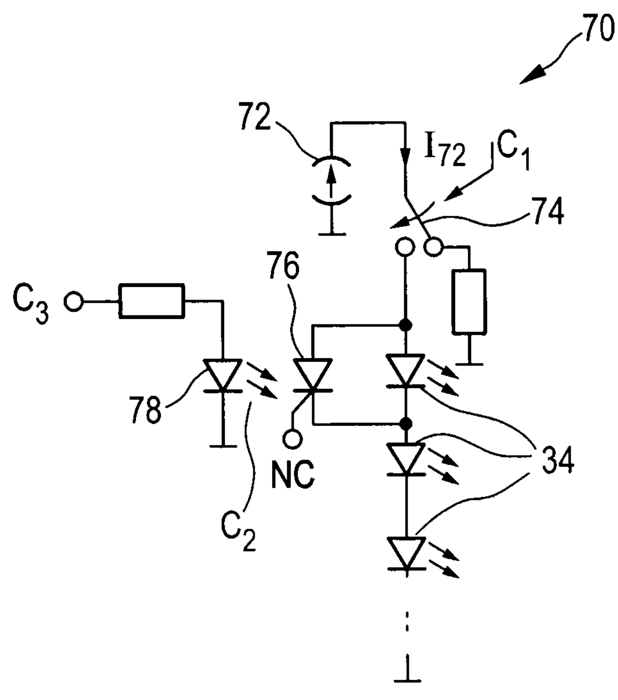

FIG. 8

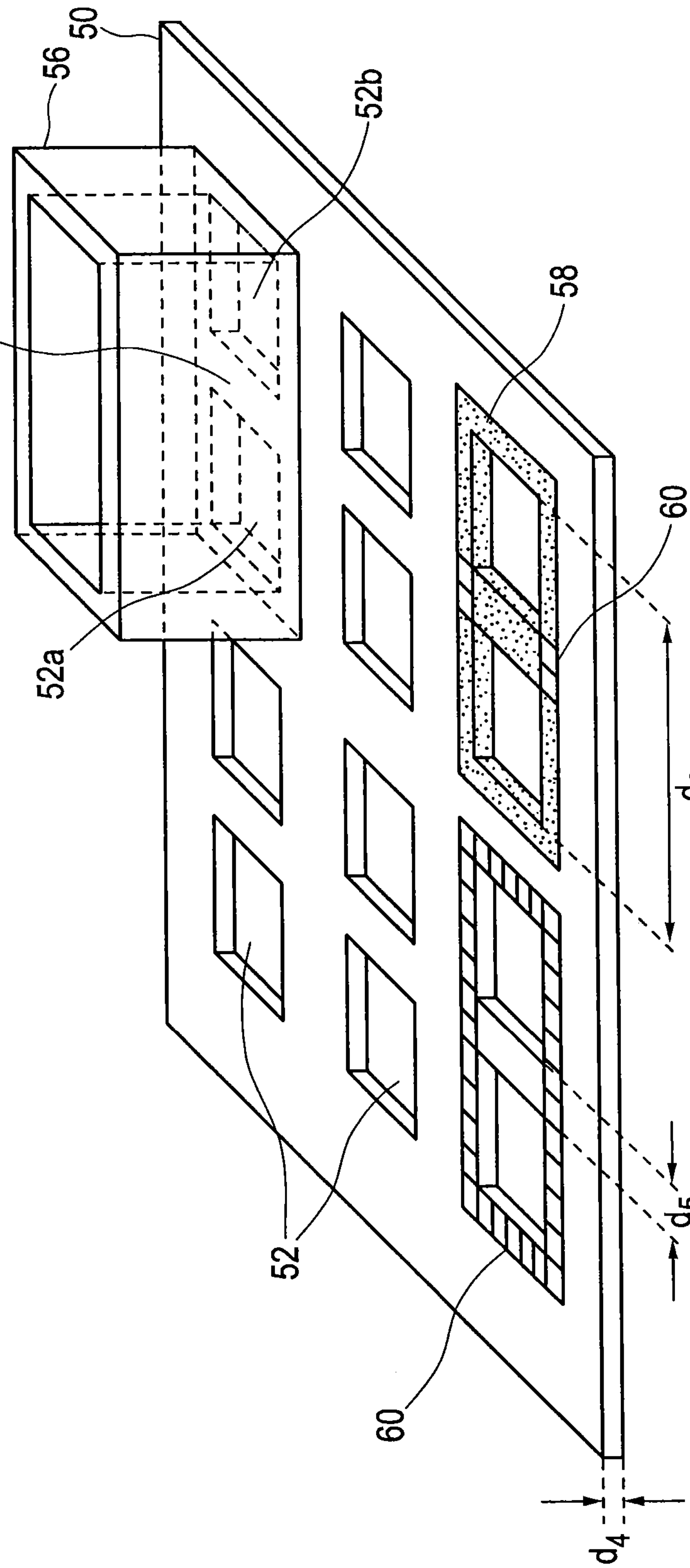

FIG. 7

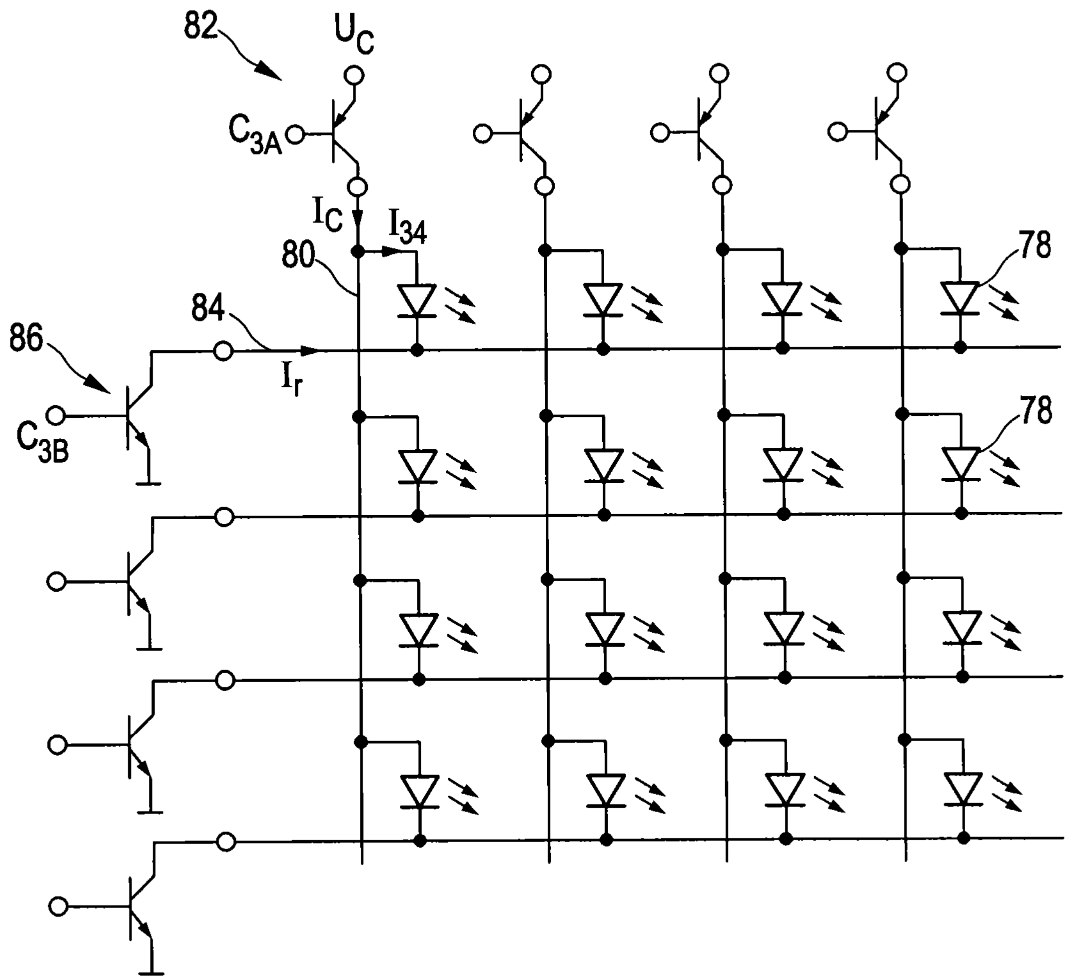

FIG. 9

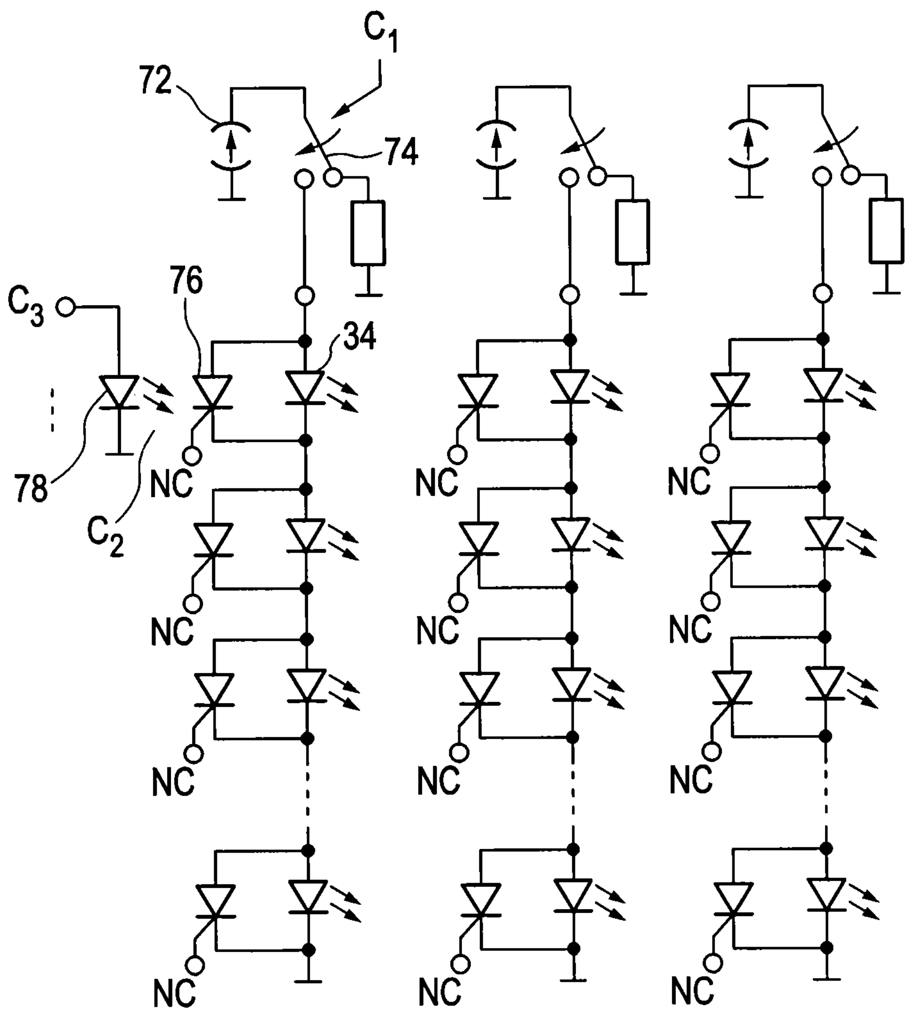

FIG. 10

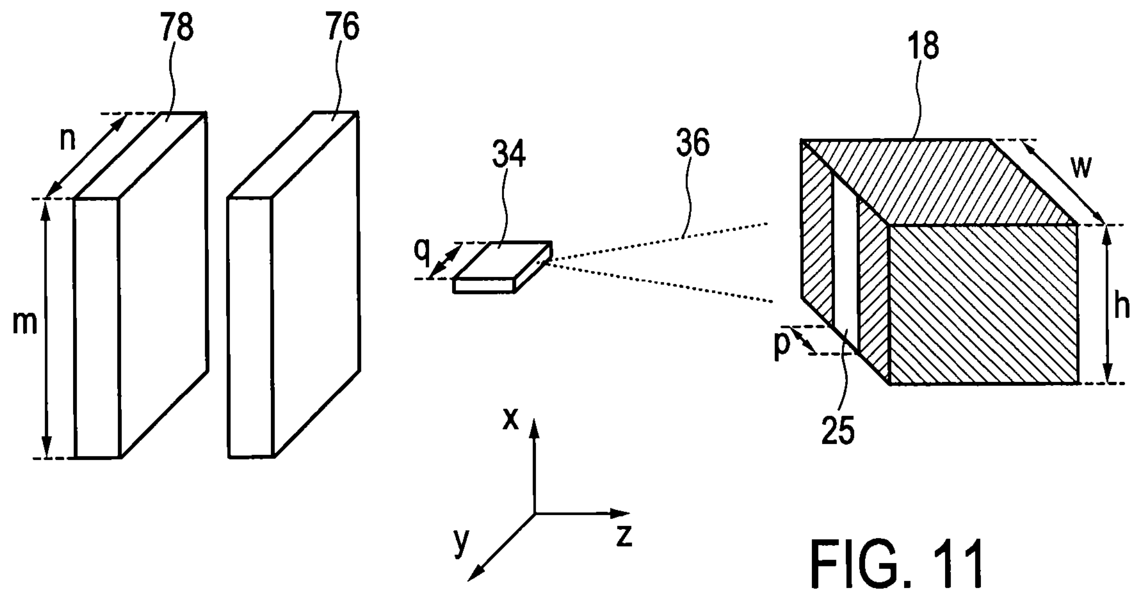

FIG. 11

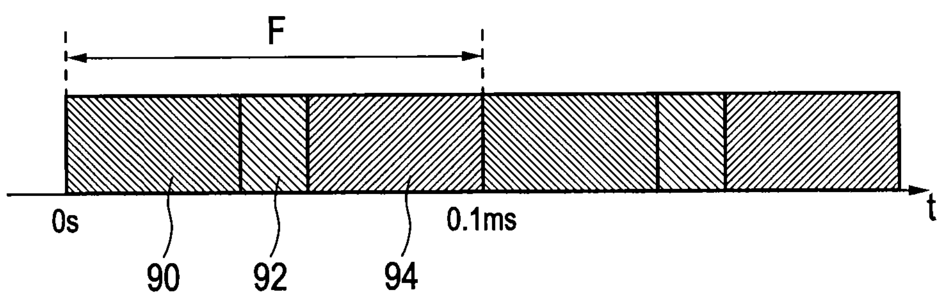

FIG. 12

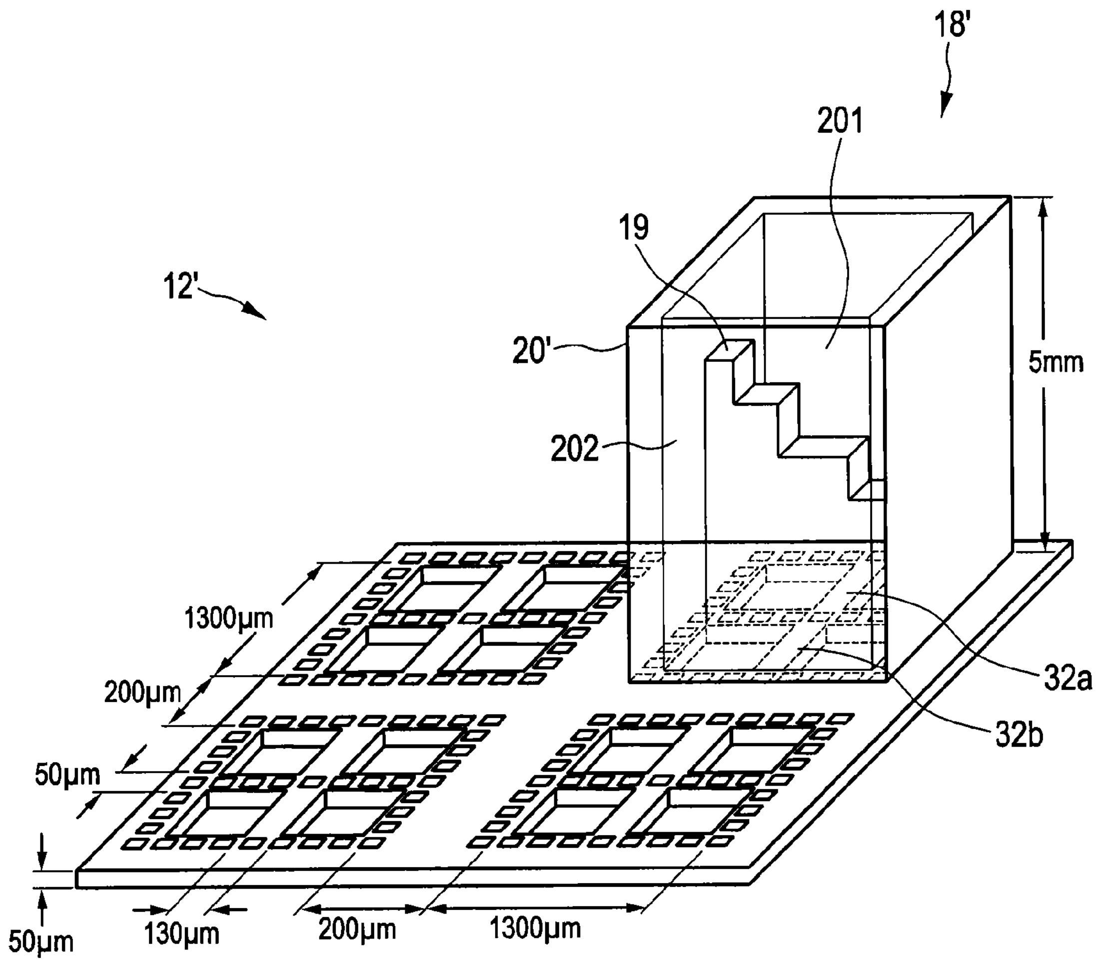
18'
201
19
12'
20'
5mm
202
1300μm
32a
200μm
32b
50μm
50μm
130μm
200μm
1300μm

FIG. 13

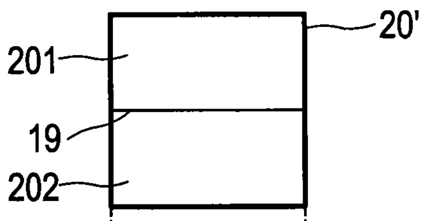

FIG. 14A

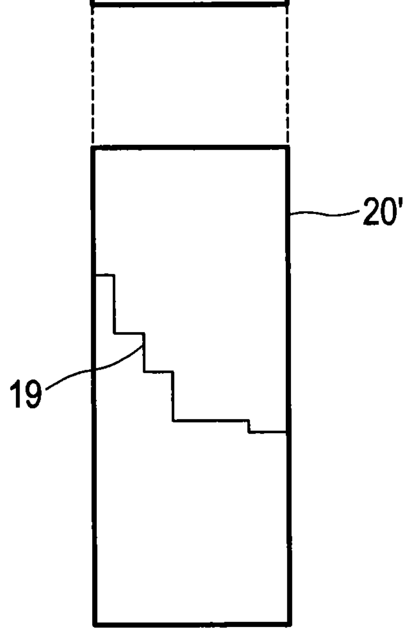

FIG. 14B

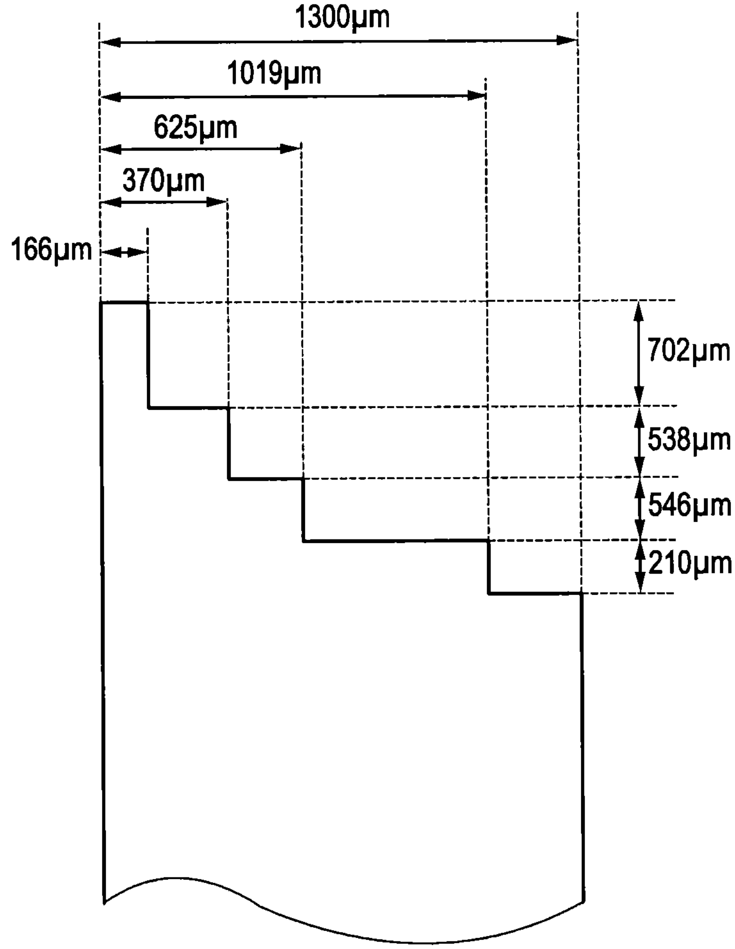

FIG. 15

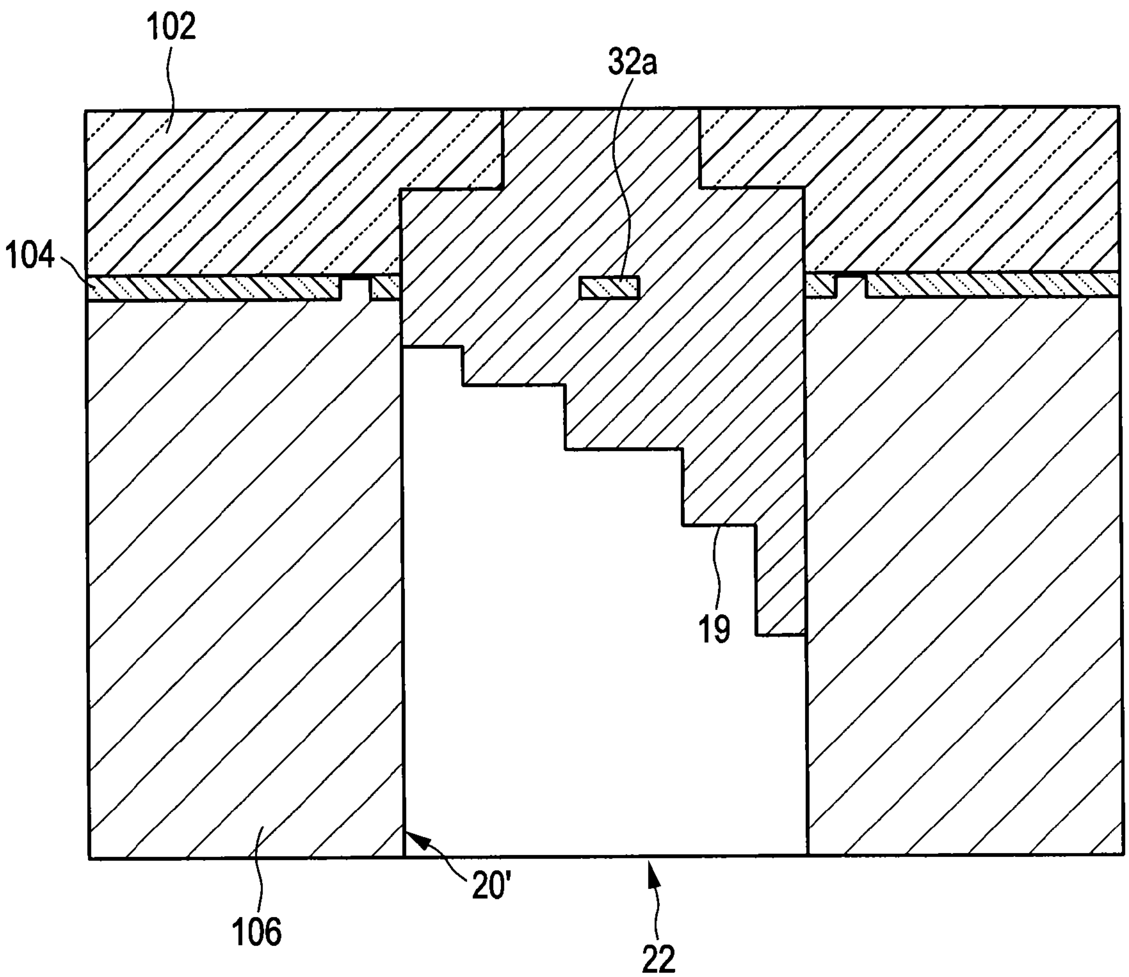

FIG. 16

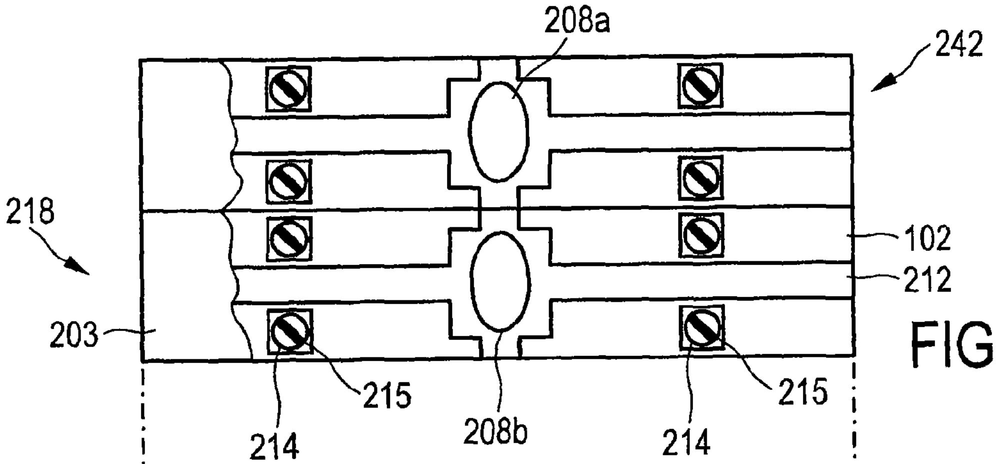

FIG. 17A

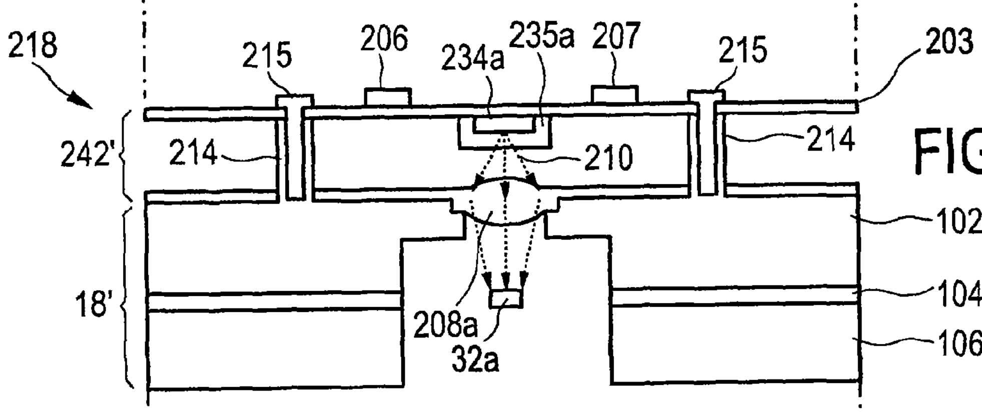

FIG. 17B

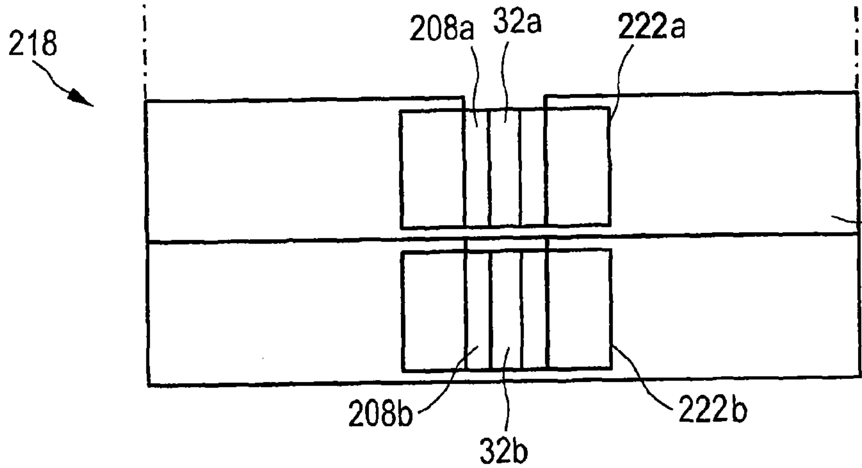

FIG. 17C

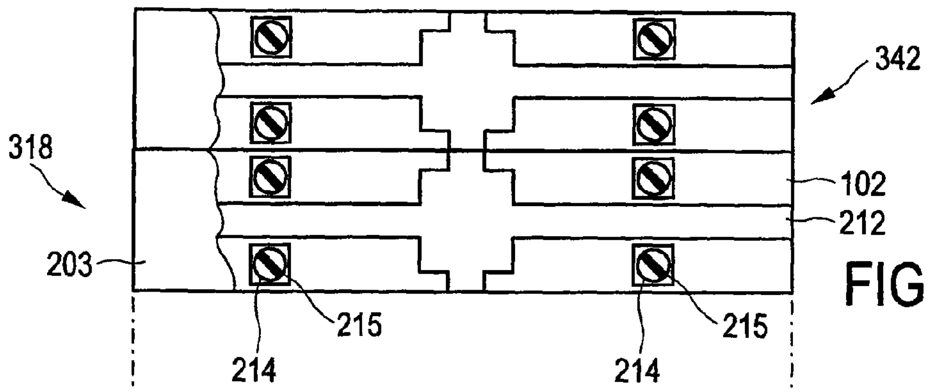

FIG. 18A

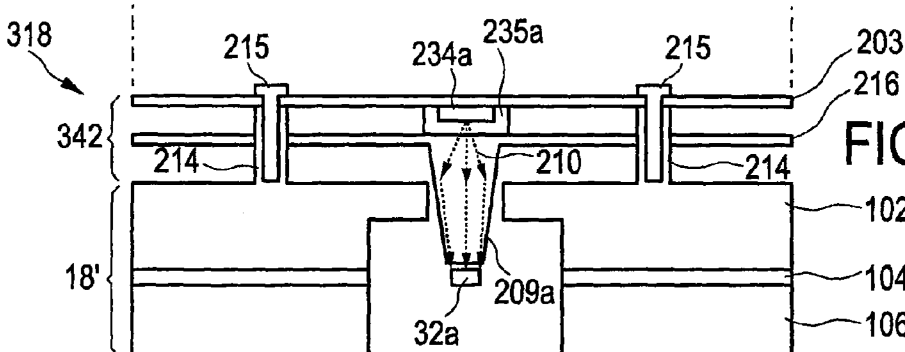

FIG. 18B

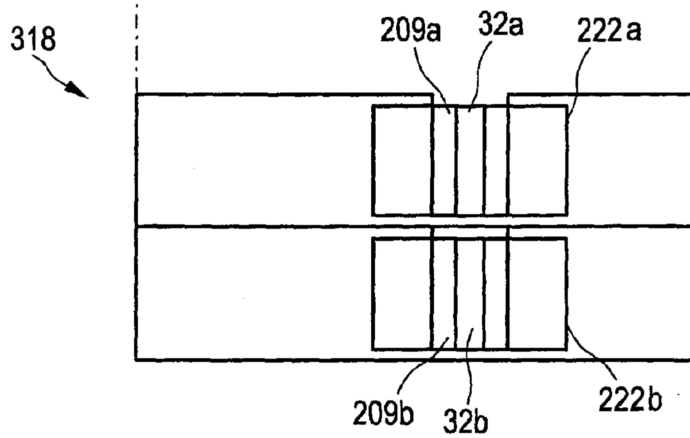

FIG. 18C

DUAL-POLARIZED OPTICALLY CONTROLLED MICROWAVE ANTENNA

CROSS-REFERENCE TO RELATED APPLICATION

The present application claims the benefit of the earlier filing date of EP 11194771.9 filed in the European Patent Office on Dec. 21, 2012, the entire content of which application is incorporated herein by reference.

BACKGROUND

1. Field of the Disclosure

The present invention relates to an optically controlled microwave antenna. Further, the present invention relates to an antenna array, in particular for use in such an optically controlled antenna, comprising a plurality of antenna elements. Still further, the present invention relates to control circuit for controlling light sources of an antenna array of a microwave antenna.

2. Description of Related Art

In millimeter wave imaging systems a scene is scanned in order to obtain an image of the scene. In many imaging systems the antenna is mechanically moved to scan over the scene. However, electronic scanning, i.e. electronically moving the radiation beam or the sensitivity profile of the antenna, is preferred as it is more rapid and no deterioration of the antenna occurs like in a mechanic scanning system.

Reflectarray antennas are a well-known antenna technology, e.g. as described in J. Huang et J. A. Encinar, Reflectarray Antennas, New York, N.Y., USA: Institute of Electrical and Electronics Engineers, IEEE Press, 2008, used for beam steering in the microwave and millimeter waves frequency range (hereinafter commonly referred to as "microwave frequency range" covering a frequency range from at least 1 GHz to 30 THz, i.e. including mm-wave frequencies). For frequencies up to 30 GHz there exist multiple technologies to control the phase of each individual antenna element of such a reflectarray antenna having different advantages and disadvantages. In particular PIN diode based switches suffer from a high power consumption, high losses and can hardly be integrated into a microwave antenna operating above 100 GHz. MEMS switches require high control voltages and have very slow switching speed. FET-based switches suffer from high insertion losses and require a large biasing network. Liquid crystal based phase shifters exhibit very slow switching speeds in the order of tenths of a second. Ferroelectric phase shifters allow rapid shifting at low power consumption, but have a significant increase in loss above 60 GHz.

Optically controlled plasmonic reflectarray antennas are described, for instance, in U.S. Pat. No. 6,621,459 and M. Hajian et al., "Electromagnetic Analysis of Beam-Scanning Antenna at Millimeter-Waves Band Based on Photoconductivity Using Fresnel-Zone-Plate Technique", IEEE Antennas and Propagation Magazine, Vol. 45, No. 5, October 2003. Such reflectarray antennas have, however, a very high power consumption. Particularly, U.S. Pat. No. 6,621,459 discloses a plasma controlled millimeter wave or microwave antenna in which a plasma of electrons and holes is photo-injected into a photoconducting wafer. In a first embodiment the semiconductor is switched between the material states "dielectric" and "conductor" requiring a high light intensity and providing a high antenna efficiency. In a second embodiment the semiconductor is switched between the two states "dielectric" and "absorber (lossy conductor)" requiring only a low light intensity and providing a worse antenna efficiency. A special distribution of plasma and a millimeter wave/microwave reflecting surface behind the wafer allows a phase shift of the individual elements of 180° between optically illuminated and non-illuminated elements in the first embodiment. The antenna can be operated at low light intensities using a mm-wave/microwave reflecting back surface with an arbitrary constant phase shift between illuminated and non-illuminated elements in said second embodiment.

In an embodiment the antenna includes a controllable light source including a plurality of LEDs arranged in an array and a millimeter wave reflector positioned in front of the light source, said reflector allowing light from the light source to pass there through while serving to reflect incident millimeter wave radiation. Further, an FZP (Fresnel Zone Plate) wafer is positioned in front of the millimeter wave reflector, said wafer being made a photoconducting material which is transmissive in the dark to millimeter waves and is responsive in the light. Finally, the antenna includes an antenna feed located in front of the wafer for illuminating the wafer with millimeter waves and/or receiving millimeter waves. By selectively illuminating the LEDs, heavy plasma density produces a 180° phase shift in out-of-phase zones. With respect to those regions where the LEDs are not illuminated, low plasma density (or "in-phase") zones are provided. Millimeter wave radiation which is incident on the high plasma density zones incurs a 180° phase change on reflection at the front surface of the wafer. Comparatively, millimeter wave radiation which is incident on the low plasma density zones incurs a 180° phase change on reflection at the millimeter wave reflector. The path length difference provides the desired overall phase shift of 180° between in-phase and out-of-phase zones. In an alternative embodiment described in this document the reflectivity of the wafer to reflect millimeter wave radiation is changed by the illumination of the light source to either allow the millimeter wave radiation to be reflected or to pass through. In another embodiment using lower light intensities the mm-wave radiation can either be absorbed by the wafer or pass through.

The "background" description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventor(s), to the extent it is described in this background section, as well as aspects of the description which may not otherwise qualify as prior art at the time of filing, are neither expressly or impliedly admitted as prior art against the present invention.

SUMMARY

It is an object of the present invention to provide an optically controlled microwave antenna having a lower power consumption compared to known optically controlled microwave antennas and providing the ability to obtain more information out of a radar image. It is a further object of the present invention to provide a corresponding antenna array for use in such an optically controlled microwave antenna.

According to an aspect of the present invention there is provided an optically controlled microwave antenna comprising:

i) an antenna array comprising a plurality of antenna elements, an antenna element comprising:

a waveguide for guiding microwave radiation at an operating frequency between a first open end portion and a second end portion arranged opposite the first end portion, said second end portion having a light transmissive portion formed in at least a part of the second end portion,

two optically controllable semiconductor elements arranged within the waveguide in front of the light transmissive portion of the second end portion, each of said semiconductor element changing its material properties, in particular its reflectivity of microwave radiation of the operating frequency, under control of incident light,

a controllable light source arranged at or close to the light transmissive portion of the second end portion for projecting a controlled light beam onto said semiconductor element for controlling its material properties, in particular its reflectivity, and

a septum arranged within the waveguide in front of the light transmissive portion of the second end portion and separating said waveguide into two waveguide portions, wherein within each waveguide portion one of said two semiconductor elements is arranged, and

ii) a feed for illuminating said antenna array with and/or receiving microwave radiation of the operating frequency from said antenna array to transmit and/or receive microwave radiation.

According to a further aspect of the present invention there is provided an antenna array, in particular for use in such an optically controlled antenna, comprising a plurality of antenna elements, an antenna element comprising:

a waveguide for guiding microwave radiation at an operating frequency between a first open end portion and a second end portion arranged opposite the first end portion, said second end portion having a light transmissive portion formed in at least a part of the second end portion,

two optically controllable semiconductor elements arranged within the waveguide in front of the light transmissive portion of the second end portion, each of said semiconductor element changing its material properties, in particular its reflectivity of microwave radiation of the operating frequency, under control of incident light,

a controllable light source arranged at or close to the light transmissive portion of the second end portion for projecting a controlled light beam onto said semiconductor element for controlling its material properties, in particular its reflectivity, and

a septum arranged within the waveguide in front of the light transmissive portion of the second end portion and separating said waveguide into two waveguide portions, wherein within each waveguide portion one of said two semiconductor elements is arranged.

Preferred embodiments of the invention are defined in the dependent claims. It shall be understood that the claimed antenna array has similar and/or identical preferred embodiments as the claimed optically controlled microwave antenna and as defined in the dependent claims.

To gain the most information out of a radar image, polarimetry can be employed. Targets converting the polarization during scattering or being invisible for a solely linear polarized radar system can be detected. By evaluating the way the target is scattering, a more detailed picture can be obtained showing some of the scattering properties of the observed targets (e.g. rough surface, lattice, parallel wires, . . .).

In order to apply polarimetric picture processing, the transmit (TX) and receive (RX) antennas emit and receive the electromagnetic field in a dual-polarized manner, i.e. dual-polarized elements with orthogonal polarization is used. Orthogonal polarizations can either be linear vertical and linear horizontal (or linear in any orientation and the perpendicular polarization), left-hand circular and right-hand circular, or orthogonally elliptical (left-hand elliptical and right-hand elliptical with orthogonal orientation of the ellipse). The elliptical case is the most general case and can cover all aforementioned cases, which are special embodiments of the elliptical one.

Polarimetric evaluation of a radar image can be applied to any of the aforementioned orthogonal polarizations. In polarimetry they are even equivalent as by basis transformation the respective receive signals of either combination can be transformed to another by mathematical means. The proposed microwave antenna can be used for scanning a scene in a polarimetric manner using left/right hand circular polarization. Orthogonal linear polarization can also be employed, but with a potential loss of full polarimetric scanning capability.

In order to generate orthogonal polarized waves in a two-dimensional reflectarray antenna, the proposed antenna array and the proposed antenna comprising such an antenna array are configured such that the waveguides are divided into two waveguide portions by a septum. Each of the waveguide portions is terminated by a photosensitive element for phase shifting, a backshort, and some optics for illumination. The septum converts a port signal fed at only one of the virtual waveguide ports of one (e.g. rectangular) waveguide portion to a circularly (elliptically) polarized wave radiated from the (e.g. quadratic) waveguide.

Further, the present invention is based on the idea to reduce the optical power, which is needed to illuminate the optically controllable semiconductor element used to generate a phase shift in the respective antenna element, by use of an antenna array comprising a plurality of antenna elements in which the antenna elements comprise an open-ended waveguide in which the microwave radiation is guided between a first open end portion and a second end arranged opposite the first end. In the vicinity of said second end portion, which is at least partially open, the optically controllable semiconductor element is placed, preferably in the form of a narrow post (or a grid array of posts as explained below), which semiconductor element changes its material properties, in particular its reflectivity for microwave radiation at the operating frequency, under control of incident light.

For instance, the semiconductor elements may be made of intrinsic semiconductor material, causing a full reflection in case of being illuminated and leading to a change of conductivity from almost 0 S/m to more than 1000 S/m. For illumination of the semiconductor elements controllable light sources are arranged at or close to the light transmissive portion, in particular an opening (or and indium tin oxide layer) of the second end portion of the waveguide, for projecting a controlled light beam onto said semiconductor elements for controlling their reflectivity. As in the known optically controlled microwave antennas such light sources may, for instance, be LEDs, laser diodes, solid state lasers or other means for emitting optical light (visible, IR, or UV) beam.

Like in the known optically controlled microwave antennas a feed is provided for illuminating the antenna array with microwave radiation of the operating frequency to transmit microwave radiation, e.g. for illuminating a scene in an active radiometric imaging system and/or for receiving microwave radiation of the operating frequency from said antenna array to receive microwave radiation, e.g. reflected or emitted from a scene scanned by a (active or passive) radiometric imaging system.

In a preferred embodiment said feed is configured to illuminate said antenna array with and/or to receive microwave radiation from said antenna array, said radiation having one or two different polarizations, in particular having one or two different linear polarizations, circular polarization or elliptical polarizations. In other words the entire antenna can either be operated in full polarimetric mode, in which the orthogonal receive signals are acquired in left/right hand circular polarization at the same time. Alternatively the antenna can be operated in either linear or vertical linear polarization, which only allows acquisition of the copolarization elements of the polarimetric scattering matrix in a sequential manner assuming the scene is static or quasi-static.

It shall be understood that according to the present invention the antenna may be used generally in the frequency range of millimeter waves and microwaves, i.e. in at least a frequency range from 1 GHz to 30 THz. The "operating frequency" may generally be any frequency within this frequency range. When using the term "microwave" herein any electromagnetic radiation within this frequency range shall be understood.

Further, the expression "light source" shall be understood as any source that is able to emit light for illuminating its associated semiconductor element so as to cause the semiconductor element to change its reflectivity to a sufficient extent. Here, "light" preferably means visible light, but also generally includes light in the infrared and ultraviolet range.

It shall also be noted that the proposed optically controlled microwave antenna and the proposed antenna array may be used as reflectarray antenna, i.e. in which embodiment the incident microwave radiation is reflected to the same side of the antenna array. In another embodiment, however, the antenna and the antenna array may be used as a transmissive array antenna in which embodiment the incident microwave radiation is incident on the antenna array on a different side than the output microwave radiation, i.e. the radiation that is transmitted through the waveguides of the antenna array is used as output in this embodiment. In this case the mm-wave signal of the optically illuminated antenna elements is reflected or absorbed. Thus, the antenna aperture efficiency is only approximately 50% of the aforementioned reflectarray.

In rapid optically controlled microwave antennas the semiconductor elements are generally controlled simultaneously, e.g. by a microcontroller or a field-programmable gate array, preferably by individual control lines. For instance, in the antenna disclosed in U.S. Pat. No. 6,621,459 the LEDs are individually controlled. This results in an overall high current and a static power consumption of the control circuit. For instance, in case each semiconductor element requires a current of 10 mA a total current of 100 A is required in case of 10000 semiconductor elements in the antenna array which is generally not applicable. Hence, in an aspect of the present invention a control circuit is proposed as defined above for controlling the light sources of an antenna array by which the current provided to the individual light sources is reduced to a small fraction of the current used conventionally. Further the total current is strongly reduced resulting in no static power consumption of the control circuit for controlling the light emitting elements such as LEDs or laser diodes.

The control circuit is preferably used in an optically controlled microwave antenna as proposed according to the present invention and/or for controlling the light sources of the proposed antenna array. However, generally the proposed control circuit can also be used in other microwave antennas having an antenna array, such as the antenna described in U.S. Pat. No. 6,621,459, in which the proposed control circuit can also lead to a significant reduction of the static power consumption of the control circuit of the light sources. Furthermore, less interconnects and wires are needed compared to a solution using a flip-flop for each antenna element.

The proposed optically controlled microwave antenna can be scaled to frequencies beyond 500 GHz maintaining low loss (1 dB) and having a reduced power consumption compared to conventional optically controlled microwave antennas, in particular plasmonic reflectarray antennas (80% less).

It is to be understood that both the foregoing general description of the invention and the following detailed description are exemplary, but are not restrictive of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the disclosure and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

FIG. **1** shows a general embodiment of an optically controlled microwave antenna according to the present invention,

FIG. **2** shows an embodiment of an antenna array,

FIG. **3** shows a perspective view of a single antenna element of such an antenna array,

FIG. **4** shows a side view of a first embodiment of a single antenna element,

FIG. **5** shows a side view of a second embodiment of a single antenna element,

FIG. **6** shows a perspective view of a third embodiment of a single antenna element,

FIG. **7** shows a second embodiment of an antenna array,

FIG. **8** shows a circuit diagram of a control unit for controlling a light source of an antenna element,

FIG. **9** shows an embodiment of a control circuit for controlling the light sources,

FIG. **10** shows an embodiment of a control circuit for controlling switchable elements coupled in parallel to said light sources,

FIG. **11** shows a perspective view of the arrangement of the components of the control unit as shown in FIG. **8**,

FIG. **12** shows a timing diagram illustrating the control of the light sources,

FIG. **13** shows a perspective view of an embodiment of an antenna array according to the present invention,

FIG. **14** shows different views of a waveguide including a septum as used in an antenna according to the present invention,

FIG. **15** shows a top view of a septum,

FIG. **16** shows a top view of a single antenna element according to the present invention,

FIG. **17** shows different views of a another embodiment of an antenna array according to the present invention, and

FIG. **18** shows different views of still another embodiment of an antenna array according to the present invention.

DESCRIPTION OF THE EMBODIMENTS

Referring now to the drawings, wherein like reference numerals designate identical or corresponding parts throughout the several views, FIG. **1** shows a general embodiment of an optically controlled microwave antenna **10** according to the present invention. The antenna **10** comprises an antenna array **12** and a feed **14** for illuminating said antenna array with and/or receiving microwave radiation **16** of the operating frequency from said antenna array **12** to transmit and/or receive microwave radiation, for instance to illuminate a scene and/or receive radiation reflected or emitted from a scene to make a radiographic image of the scene. The feed **14** may be a small microwave radiation horn or the like, or may be embodied by a small sub-reflector in case of a Cassegrain or backfire-feed type construction. The feed **14** may be connected (not shown) to a microwave radiation source (transmitter) and/or to a microwave receiver as required according to the desired use of the microwave antenna **10**. The antenna array **12** comprises a plurality of antenna elements **18**, the reflectivity of which can be individually controlled as will be explained below so that the total antenna beam reflected from or transmitted through the antenna array can be electronically steered to different directions as needed, for instance, to scan a scene. Particularly, the phase of reflected or transmitted microwave radiation of the individual antenna elements **18** can be individually controlled.

In the embodiment shown in FIG. **1** the antenna elements **18** are regularly arranged along rows and columns of a rectangular grid, which is preferred. However, other arrangements of the antenna elements **18** of the antenna array **12** are possible as well. A perspective view of an antenna array **12** that may be used in an antenna **10** shown in FIG. **1** is depicted in FIG. **2**. A single antenna element **18** is depicted in FIG. **3** in a perspective view. The antenna element **18** comprises a waveguide **20** for guiding microwave radiation at an operating frequency between a first open end portion **22** and a second end portion **24** arranged opposite the first end portion **22**, said second end portion **24** having an opening **25** (generally a light transmission portion) formed in at least a part of the second end portion **24**. The antenna array **12** is preferably arranged such that the first open end portion **22** is facing the feed **14**. Preferably, the rectangular waveguide **20** is operated in its fundamental TE_{10} mode.

The waveguide **20** is formed in this embodiment by a tube-like waveguide structure having two opposing left and right sidewalls **26**, **27**, two opposing upper and lower sidewalls **28**, **29** and a back end wall **30**, which sidewalls **26** to **30** are preferably made of the same metal material configured to guide microwave radiation.

The antenna element **18** further comprises an optically controllable semiconductor element **32**, preferably formed as a post, arranged between and contacting the opposing upper and lower sidewalls **28**, **29** of the waveguide **20**. The semiconductor element **32** is arranged within the waveguide **20** in front of the opening **25** of the second end portion **24**, preferably at a predetermined distance from said opening **25** and closer to said second end portion **24** than to said first end portion **22**. Said semiconductor element **32** is configured to change its material properties from dielectric to conductor under control of incident light. For instance, in an embodiment said semiconductor element is able to cause a full reflection within the waveguide **20** in case it is illuminated and to cause no or only low reflection (e.g. full transmission) in case it is not illuminated, i.e. the total reflection changes under control of incident light. Preferably said semiconductor element **32** is made of a photo-conducting material such as elemental semiconductors including silicon and germanium, another member of the category of III-V and II-VI compound semiconductors or graphene.

It should be noted that, while the semiconductor element herein is shown as having the form of a post, the semiconductor element may also have alternative geometries as long as it fulfills the desired function as described herein. Sometimes such an element is also referred to as a controllable short.

The antenna element **20** further comprises (not shown in FIGS. **2** and **3** but in FIGS. **4** and **5** showing side views of different embodiments of antenna elements **18***a*, **18***b*) a controllable light source **34** arranged at or close to the opening **25** of the second end portion **24** for projecting a controlled light beam **36** through said opening **25** onto said semiconductor element **32** for controlling its material properties. Due to the change of the material properties of the semiconductor material, the entire antenna element will change the phase of the reflected signal. Said light source **34** may be an LED or a laser diode, but may also include an IR diode or a UV light source in case the semiconductor element **32** is configured accordingly to change its reflectivity in response to incident IR or UV light.

As shown in FIG. **2** the antenna elements **18** are arranged next to each other so that they are sharing their sidewalls. Preferably, the waveguides **20** have a rectangular cross-section having a width w (between the left and right sidewalls **26**, **27**) of substantially a half wavelength ($0.5\lambda<w<0.9\lambda$) and a height h (between the upper and lower sidewalls **28**, **29**) of substantially a quarter wavelength ($0.25\lambda<h<0.452$) of the microwave radiation of the operating frequency. By use of such a dimensioning of the waveguide **20** it is made sure that only the fundamental TE_{10} mode of the microwaves is guided through the waveguide **20**. Further, since only the fundamental TE_{10} mode can propagate within the waveguide, it can be assured that the radiation pattern always looks the same, independent from how homogenous the semiconductor element **32** is illuminated.

As shown in the side view of FIG. **4** the semiconductor element **32** is preferably arranged at a distance d_1 from the second end portion **24** of substantially a guided quarter wavelength ($\lambda_g/4$) of the microwave radiation of the operating frequency in case the signal is reflected at the back short of the waveguide. To fix the semiconductor element **32** a support element **38**, e.g. a support layer, of a low loss air-like material (e.g. Rohacell) with $\epsilon_r \approx 1$ is used. Generally, the thickness d_0 of the support element is not essential as long as the losses are negligible, it could e.g. in the same range as the distance d_1. Said support element **38** can, as shown in FIG. **4**, be arranged on the side of the semiconductor element **32** facing the first end portion **22** but could also be arranged on the side facing the second end portion **24** if it is optically translucent. Preferably, said support element **38** is arranged (contacted) between the upper and lower sidewalls **28**, **29** of the waveguide **20**.

Alternatively or in addition to the support element **38** one or more antireflection elements **40**, **42**, for instance dielectric antireflection layers, may be arranged on one or both sides of the semiconductor element **32** as shown in the embodiment of the antenna element **18***b* shown in FIG. **5**. Said antireflection elements **40**, **42** preferably have a thickness d_2, d_3 of substantially a guided quarter wavelength ($\lambda_g/4$) of the microwave radiation of the operating frequency and serve to reduce any losses caused by any mis-match of the semiconductor material. While the antireflection element **40** only needs to be translucent for the microwave radiation, the antireflection layer **42** additionally needs to be translucent for the light **36** emitted by the light source **34**.

Generally, it has shown that 20% of the width of the waveguide **20** is a reasonable size for the width of the semiconductor element **32**. In this way the overall power can be reduced by approximately 80%. Generally, the width of the semiconductor element **32** is in the range from 5% to 50%, in particular from 10% to 30% of the width w of the waveguide **20**.

The opening **25** of the end portion **24** of the waveguide **20** preferably takes at a portion of 5% to 75%, in particular of 10% to 50%, of the total end area of the second end portion **24**. The size of the opening **25** depends on the type of application of the antenna array. If the antenna array **12** shall be used as a reflectarray the opening **25** must not be too large so that microwaves transmitting through the semiconductor element **32** in the non-illuminated state are reflected at the back end wall **30** and are not completely transmitted through the waveguide **20**.

If, however, the antenna array **12** shall be used as a transmissive array a waveguide-to-microstrip transition and a microstrip-to-waveguide transition are employed (see the embodiment depicted in FIG. **7**E that will be explained below). Then, in one state the microwaves are reflected or absorbed by the semiconductor element **32** placed in the microstrip line. In this case only 50% of the energy is transmitted, i.e. the antenna aperture efficiency is reduced by 50%.

In another embodiment, said opening **25** is covered by a light transmissive layer (not shown), such as an indium tin oxide (ITO) layer, provided at the second end portion **24** through which the light **36** emitted from the light source **34** is transmitted onto the semiconductor element **32**. The ITO layer reflects the microwaves, i.e. it is a conductor for microwaves and translucent for optical light. Further, the ITO layer covers the complete area of the second end **24**, i.e. no back end wall **30** is required, but an optically translucent carrier material is used. This material is outside the waveguide and in front of the light emitting element.

Another embodiment of an antenna element **18***c* is depicted in a perspective view in FIG. **6** (showing two of such antenna elements **18***c*). In this embodiment an aperture element **44**, for instance a symmetric quadratic pyramidal aperture, is arranged in front of the first end portion **22** of the waveguide **20** having a larger aperture **46** than the first end portion **22** of the waveguide **20**. By this aperture element **44** the incident microwaves are guided into the waveguide **20** having a smaller cross-section so that the semiconductor element **32** can also be made smaller than in the embodiment of the antenna element **18***a*, shown, for instance, in FIG. **3**. Consequently, less optical power is required to illuminate the semiconductor element **32** to switch its state of reflectivity so that in total the optical power can be further reduced up to 90% compared to known optically controlled microwave antennas.

A preferred embodiment for manufacturing an antenna array **12** shall be illustrated by way of FIG. **7**. This figure depicts a grid **50** made of semiconductor material, in particular made of Si. In said grid **50** holes **52** have been formed, in particular by etching, wherein between two neighboring holes **52***a*, **52***b* a post **54** of said semiconductor material remains, said post **54** representing the semiconductor element **32**. Onto said grid **50**, preferably on both sides, the waveguides **20** are formed by an array of tubes or tube-like structures having two open ends, wherein said array of tubes is coupled to said grid **50** and arranged such that an open end of a tube **56** covers two neighboring holes **52***a*, **52***b* and the post **54** formed there between.

In an exemplary implementation for 140 GHz the thickness d_4 of the grid **50** may be approximately 50 μm, the width d_5 of the post **54** may be approximately 300 μm and the width d_6 of the two neighboring holes **52***a*, **52***b* including the post **54** may be approximately 1500 μm. Further, in an embodiment a conductive coating **58**, e.g. made of gold, may be provided at the inner sidewalls of said holes **52***a*, **52***b* to further improve the ability to guide microwaves within said holes **52***a*, **52***b*. This is only exemplarily shown for two neighboring holes. Further, in an embodiment vias **60** are provided at the top and bottom of the post **54** to continue the walls of the rectangular waveguides **56** put on the top and bottom of the semiconductor grid **50**. Instead of using a metal plating, the entire outline of the waveguide can be covered with vias as depicted exemplarily in FIG. **7**.

Preferably, the light sources **34** of the antenna array **12** are also arranged in a light source matrix (not shown), in particular on a light source carrier structure. In an embodiment, said light source carrier structure can be easily coupled to the grid **50** and the light sources are arranged in said light source carrier structure with distances corresponding to the distances of the posts **54** in the grid **50**.

An array of a large number, e.g. 10000, antenna elements (covering, for instance, an area of approximately 10 cm×10 cm at an operating frequency of 140 GHz) requires a large number of control lines if the light sources **34** were individually controlled to illuminate the respective semiconductor elements **32**. In principle, each semiconductor element **32** should be controlled individually. Connecting each light source **34** of a light source matrix to an output of a control circuit, such as a microcontroller or FPGA, would result in a high overall current consumption which cannot be handled by the control circuit, Thus, according to an aspect of the present invention a control circuit is provided for controlling light sources of an antenna array, in particular an antenna array as proposed according to the present invention, of a microwave antenna, in particular as proposed according to the present invention. A circuit diagram of a single control unit **70** of such a control circuit is shown in FIG. **8**. As shown in the circuit diagram the light sources **34** within a row or column are connected in series and are driven by a current source **72** that, for instance, provides a drive current I_{72} of 10 mA. Said drive current I_{72} can be switched on and off by use of an electronic switch **74** which is switched on and off under control of a first control signal C_1 (also called line control signal). By coupling the light sources **34** within a row or column in series and driving them by the common current source **72** the overall current can also be reduced.

In parallel to the individual light sources **34** a switchable element **76** is provided that can be switched on and off under control of a second control signal C_2 (also called switching element control signal). When said switchable element **76** is switched on, the light source **34** coupled in parallel is shorted so that the light source **34** is switched off, i.e. does not emit light. The switchable element **76** is preferably formed by a thyristor or a triac, in particular a photo-thyristor or photo-triac.

The second control signal C_2 is provided by a switching element **78** which is configured for switching said switchable element **76** on and off. Preferably, said switching element **78** is formed by a diode, in particular an IR diode, and the second control signal C_2 is a radiation signal emitted by said diode **78**. Said switching element **78** in turn is controlled by a third control signal C_3, e.g. provided by a microcontroller or a processor.

Assuming in a practical implementation a voltage drop of 1 to 4 V at each light source **34**, the voltage at the top light source of a row or column can sum up to a few 100 volts. A photo-thyristor used as the switchable element **76** allows simple voltage level shifting without a galvanic connection to the control circuitry controlling the switching element **78** running at low voltage. Once switched on, the switchable element **76** remains switched on until the supply current I_{72} is turned off for which purpose the switch **74** is provided which switches the entire row or column on and off.

More details of the proposed control circuit are shown in the circuit diagrams depicted in FIGS. **9** and **10**. FIG. **9** shows particularly the control circuitry for providing the light sources **78** with the required optical control signals. As shown in FIG. **9** an array of, for instance, 100×100 light sources **78** are provided as light source matrix, i.e. an array of rows and columns, each light source **78** covering, for instance, an area of 1.5 mm×1.5 mm (at 140 GHz) at maximum. For each column a column control line **80** is provided. To each column a column drive current I_c of e.g. 500 mA is provided through a column switch **82** (e.g. a bipolar transistor) from a voltage source (not shown) providing a column voltage U_c of e.g. 1.5 V. Said column switches **82** are controlled by column control signals C_{3A}. Thus, a light source current I_{34} of e.g. 5 mA runs through each light source **78**. Further, row control lines **84** are provided through which a row drive current I_r of e.g. 5 mA is fed through a row switch **86** (e.g. a bipolar transistor) which is controlled by a row control signal C_{3B}.

FIG. **10** shows the control circuitry for controlling the switchable elements **76** through the switching elements **78** as explained above with reference to FIG. **8**. As explained above a single switchable current source **72** drives each column of light sources **78**. However, in an embodiment a single current source and a multiplexer can be used for all columns. For each switchable element **76** a switching element **78** controlled by a third control signal C_3 is provided.

Considering a particular implementation, FIG. **9** shows a matrix of LEDs **78**, which are used to control the photo-thyristors **76**. Using a matrix structure reduces the number of outputs of a microcontroller used to configure the matrix. FIG. **10** shows the columns of laser diodes **34** used to illuminate the semiconductor elements. Using a column arrangement can reduce the overall current and the wires used for interconnections. The LEDs **78** control the photo-thyristors **76**, which in turn switch the laser diodes **34** on and off. Configuration of the entire array requires a sequential setup of all columns.

FIG. **11** schematically shows the arrangement of main components of the control unit **70** shown in FIG. **8**. In particular, a light source **34** for emitting a light beam **36** through the opening **25** in the antenna **18** is shown as a side radiating laser diode. Further, the switching element **76** in the form of a photo-thyristor or triac is shown arranged next to the light source **34**. The switching element **78**, e.g. an IR diode, is arranged next to the switchable element **76**. These components are stacked in z-direction and have a maximum size m×n of 1.5 mm×1.5 mm in x-y-direction (typically a size of 1 mm×1 mm) for an operating frequency of 140 GHz, just to give an example. The laser diode **34** has, for instance, a width q of 0.5 mm and the opening **25** has, for instance, a width p of 0.5 mm. The antenna element **18** has, for instance, a height h of 0.75 mm and a width w of 1.5 mm.

For proper operation a special control sequence is preferably used as is schematically depicted in the timing diagram of FIG. **12**. Said control sequence is also referred to as a frame F. Considering the use of the proposed antenna in an imaging device for imaging a scene, the acquisition of one pixel of an image to be taken starts with a reset phase **90**. During this reset phase **90** all switches **74** of all columns/rows are switched off, so that all light sources are switched off. Then, the switches **74** are turned on sequentially and in the setup phase **92** all columns/rows are configured sequentially by the control circuit, which limits the current through the control circuit. For this setup phase a switching element **78** is briefly switched on so that the corresponding light source is briefly switched off. When all light sources or columns/rows are configured, the measurement phase **94** can start during which all light sources have the desired state and the desired data, e.g. for one pixel, can be acquired.

In summary, in the above an optically controlled microwave antenna, in particular a plasmonic reflectarray antenna, has been described in which the reflection (or transmission) of the antenna elements of an antenna array can be controlled by optical illumination of an intrinsic semiconductor which is placed inside an open ended waveguide and represents a reconfigurable short. The phase of the reflected (or transmitted) microwave signal of each semiconductor element can be controlled in a binary manner by switching between 0° and 180°. Compared to known optically controlled microwave antennas the proposed antenna requires approximately 80% to 90% less optical power and has lower losses, in particular below 1 dB. This is particularly achieved since the area which must be illuminated to control the single semiconductor elements is strongly reduced. Further, compared to known antennas comprising a bulk semiconductor, a well-defined radiation pattern can be achieved for each semiconductor element which is beneficial for the total antenna pattern.

Furthermore, according to another aspect a control circuit has been described which reduces the overall current, allows simple voltage level shifting and has no static power consumption.

Those plasmonic reflectarray antennas using open-ended waveguides as individual elements offer lower loss, higher optical efficiency, and lower mutual coupling compared to commonly used solutions employing patch antennas. In order to evaluate all information content contained in the acquired data in a polarimetric fashion, antenna elements exhibiting dual polarization are needed. Up to now no plasmonic reflectarray consisting of open-ended waveguides exists having this feature. Therefore, in the following, based on a modification of the above described antenna and antenna array, a solution is presented to realize a 2D plasmonic reflectarray antenna exhibiting dual polarization. The polarization can either be linear orthogonal or circularly (elliptically) orthogonal. The polarization can also be switched between different states when reflected at the open-ended waveguides. Thus, polarimetric measurements are possible, particularly when operated either with a single linearly polarized feed or a dual-polarized left-/right hand circularly polarized feed.

FIG. **13** shows a perspective view of an embodiment of an antenna array **12'** according to the present invention. Compared to the antenna array **12** described above (and e.g. shown in FIG. **7**), an antenna element **18'** of this antenna array **12'** additionally comprises a septum **19** arranged within the waveguide **20'** in front of the light transmissive portion of the second end portion of the waveguide **20'**. Said septum **19** separates said waveguide **20'** into two waveguide portions **201**, **202**, wherein within each waveguide portion **201**, **202** one of two semiconductor elements **32***a*, **32***b* is arranged. Such a septum is generally known in the art, e.g. from R. Behe and P. Brachat, "Compact Duplexer-Polarizer with Semicircular Waveguide," IEEE Trans. On Antennas and Propagation, vol. 39, no. 8, pp. 1222-1224, August 1991.

FIG. **14** shows a front view (FIG. **14**A) and a cross sectional view (FIG. **14**B) of a waveguide **20'** of an antenna element **18'** according to the present invention. As shown in this embodiment the aperture (FIG. **14**A) is made up of quadratic open-ended waveguide **20'** instead of rectangular ones as in the above described embodiments. Each of the quadratic waveguides **20'** is divided into two rectangular waveguide portions **201**, **202** by the septum **19**. The septum **19** converts a port signal fed at only one of the virtual rectangular waveguide ports (of a single waveguide portion) to a circularly (elliptically) polarized wave radiated from the quadratic open ended waveguide.

The following table summarizes the function of the septum **19**, when virtually feeding the waveguide **20'** by either of the rectangular waveguide portions **201**, **202** or both rectangular waveguide portions **201**, **202** at the same time. In operation the incident wave is reflected at the back short or the photosensitive element, respectively.

Port 1 phase	Port 2 phase	Resulting polarization
X	—	Left hand circular
—	X	Right hand circular
X	X	Linear vertical
X	X + 180°	Linear horizontal

As explained above the reflectarray **12** is fed by a feed horn **14** placed in front of the reflectarray **12**. This feed horn **14** can also exhibit different polarizations, e.g. under control of a feed control unit (not shown) for controlling said feed horn **14** to illuminate said antenna array **18'** with and/or to receive microwave radiation having a predetermined polarization from said antenna array. The following table lists the overall functionality of the reflectarray (exemplarily for the transmit mode) and the setting of the individual semiconductor elements **32***a*, **32***b* to achieve one-bit phase shifts required for beam steering. For this purpose, configurations included in the same row and exhibiting a phase shift of 180° can be used.

In the following table it can also be observed that by appropriately setting the phase shifts, the linear polarization can be changed from horizontal to vertical or vice versa.

Real polarimetric measurements, which require the transmission of one polarization and the reception of two orthogonal polarizations at the same time, are only applicable for circular polarization. In this case the feed antenna transmits in one circular polarization and both independent left/right hand circular polarized beams of the reflectarray are steered to the same position.

In order to acquire orthogonal linear components of a scene, two sequential measurements are necessary. The beam of the feed antenna transmitting in one linear polarization can be steered using the reflectarray, which may result in either the co- or cross-polarized field of the feed.

Feed polarization	Virtual port 1 phase	Virtual port 2 phase	Resulting polarization	Resulting phase shift
Linear	X	X	Linear horizontal	0°
horizontal	X + 180°	X + 180°	Linear horizontal	180°
	X	X + 180°	Linear vertical	0°
	X + 180°	X	Linear vertical	180°
Linear	X	X	Linear vertical	0°
vertical	X + 180°	X + 180°	Linear vertical	180°
	X	X + 180°	Linear horizontal	0°
	X + 180°	X	Linear horizontal	180°
Left hand	X	—	Left hand circular	0°
circular	X + 180°	—	Left hand circular	180°
Right hand	—	X	Right hand circular	0°
circular	—	X + 180°	Right hand circular	180°

A practical realization, compared to the linear polarized reflectarray antenna, substantially differs in the arrangement of the open ended waveguides and the shape of the top cover. A diagram of the photosensitive thin silicon center layer and one exemplary dual-polarized open ended waveguide **20'** is shown in FIG. **13**. Typical dimensions are given for an operating frequency of 140 GHz. For instance, the septum **10** has a thickness of 50 μm and the number of sections (steps) is between 3 and 10, typically 5 or 6. The dimensions of the septum can vary and are normally determined by numerical electromagnetic field simulations. As an example it can be referred to FIG. **15** showing an exemplary implementation of a septum **19**, where some exemplary numbers are given.

The layer stack-up shown in FIG. **16** is similar to the linear-polarized reflectarray. In the dual-polarized case the thin silicon center layer **104** exhibits vias and a metallization around the outer opening. It is placed on the plane surface of the backshort layer **102**. On top of the center layer **104** the open ended waveguide structure is placed, which also contains the septum **19** separating a pair of two rectangular waveguide portions, which together form a quadratic open-ended waveguide **20'** on the aperture of the antenna. Due to the length of the septum **19** and the quadratic waveguide section **20'**, the top layer **106** is typically fabricated by micromolding from a conductive polymer or a polymer, which is coated with some conductive layer (it can also be made of metal or a metallized silicon layer). All layers are preferably bonded together using a conductive adhesive.

As shown in FIG. **14** in each dual-polarized waveguide element **20** two rectangular waveguide portions **201**, **202** are stacked upon their small side, so that the overall aperture is quadratic. The rectangular waveguide portion **201**, **202** are separated by a septum **19**, which converts the linear polarization in either of the rectangular waveguides into a circular (elliptical) polarization in the quadratic waveguide. The attachment and excitation of the photosensitive bar (**32***a*, **32***b*) may be in any form as described above for the linear polarized reflectarray elements.

The shape of the cross section of the two stacked waveguide portions **201**, **202** can also exhibit other shapes than rectangular (quadratic), for instance a half-circular or half-elliptical cross section is possible for each waveguide portion so that the waveguide has a circular or elliptical cross section.

Furthermore it should be mentioned that the aperture of the individual waveguide portions are not limited to simple open ended waveguides. There can also be pyramidal horns, conical horns or corrugated (scalar) horns employed as explained above. For any of the horns the spacing between the individual open ended waveguide portions becomes larger due to the larger aperture diameter of the horn compared to a solution using only open ended waveguides.

In case of the usage of conical or corrugated horns a waveguide transition from the quadratic to a circular waveguide is needed. The simplest solution is a circular waveguide directly attached to the quadratic waveguide using the same diameter as one side of the quadratic waveguide. More sophisticated solutions employ a long smooth transition, which converts the quadratic cross section continuously into a circular one. However, the simplest approach is using two half-circular waveguides instead of rectangular ones carrying the photosensitive silicon.

In order to properly illuminate the photosensitive bars, i.e. the semiconductor elements **32***a*, **32***b*, particularly for an antenna array **12'** according to the present invention as e.g. shown in FIG. **13**, an optical system is employed, which is generally located on the back side of the antenna array **12'**. FIG. **17** shows an antenna element **218** of a simple embodiment of an antenna array, wherein FIG. **17**A shows a back view of only the illumination unit **242**, FIG. **17**B shows a cross sectional top view and FIG. **17**C shows a front view. The illumination unit **242** of this embodiment of the antenna comprises a printed circuit board (PCB) **203** carrying a two top radiating LEDs (only on LED **234***a* is shown), one for each semiconductor element **32***a*, **32***b*, and some control logic **206** and/or other required electronics **207**. On top of each LED **234***a* (preferably with polymer coating **235***a*) a lens **208***a*, **208***b* is placed, which focuses the optical beam **210** onto the respective photosensitive bars **32***a*, **32***b*. The lenses **208***a*, **208***b* can be molded structures forming a grid **212** for the whole array. The illumination unit **242** is coupled to the front part of the antenna element, which may correspond to the part of the antenna element **18'** shown in FIG. **13**, by use of posts or distance elements **214** and e.g. screws **215**. In FIG. **17**C the waveguide openings **222***a*, **222***b* of the waveguide portions **201**, **202** can be seen. Further, a back short layer **102**, a center layer **104** and a top layer **106** are shown in FIG. **17**B.

FIG. **18** shows an antenna element **318** of another embodiment of an antenna array, wherein FIG. **18**A shows a back view of only the illumination unit **342**, FIG. **18**B shows a cross sectional top view and FIG. **18**C shows a front view. In this embodiment dielectric rods **209***a*, **209***a*, one for each semiconductor element **32***a*, **32***b*, are used as optical guide to focus the optical beam **210** onto the respective center bar **32***a*, **32***b*. Such rods can be molded from a polymer and should end at a short distance before the photosensitive element **32***a*, **32***b*. If they do not touch, mechanical stress can be reduced. The dielectric rods **209***a*, **209***b* are held in this embodiment by a grid or holding bars **216**. Further, the LEDs **234***a* and polymer coating **235***a*, respectively, may be glued to the end of the dielectric rods **209***a*, **209***b*. In general, a solution with an optical guide has a higher efficiency than a solution using a lens as shown in FIG. **17**. Generally any kinds of optical waveguides may be used as rods **209***a*, **209***b*.

In still another embodiment, based on the embodiment shown in FIG. **18**, the entire antenna structure is fabricated out of a single layer. There is no center layer **104**. Thus, the photosensitive bars are diced rectangular chips, which are glued with optically translucent adhesive to the tip of the dielectric rods. The rods thus have two functions: they must mechanically hold the photosensitive element and they must guide the optical light from the light source to the photosensitive elements. The antenna structure can be fabricated out of any material, which is electrically conductive or has a conductive coating.

The presented dual-polarized reflectarray allows polarimetric radar measurements by either using a dual polarized feed exhibiting orthogonal left- and right hand circular (elliptical) polarization or a simple linear polarized feed. The latter makes use of the capability of the reflectarray to switch the polarization between two orthogonal states. In this measurement mode both orthogonal linear polarizations must be acquired sequentially. Due to the rapid scanning capability a scenario can be regarded static for the time of the acquisition of both polarizations.

In order to acquire a picture by a mm-wave imaging system a narrow antenna beam is scanned across the scene. Therefore, 2D/3D electronic scanning is desirable. Electronic beam scanning antenna technologies have many further application such as wireless communication systems (to enable a tracking within a mm-wave point-to-point wireless link) or radar tracking applications. Reflectarray antennas have shown to be a powerful means to apply electronic scanning using only a single transmit or receive antenna,

Plasmonic reflectarray antennas using open ended waveguides as individual elements offer lower loss, higher optical efficiency, and lower mutual coupling compared to commonly used solutions employing patch antennas.

In summary, according to the present invention a solution to realize a 2D plasmonic reflectarray antenna exhibiting dual polarization is provided. The polarization can either be linear orthogonal or circularly (elliptically) orthogonal. The polarization can also be switched between different states when reflected at the open coded waveguides. Thus polarimetric measurements are possible, when operated either with a single linearly polarized feed or a dual-polarized left-/right hand circularly polarized feed.

The invention can be applied in various devices and systems, i.e. there are various devices and systems which may employ an antenna array, an antenna and/or a control circuit as proposed according to the present invention. Potential applications include—but are not limited to—a passive imaging sensor (radiometer), a radiometer with an illuminator (transmitter) illuminating the scene to be scanned, and a radar (active sensor). Further, the present invention may be used in a communications device and/or system, e.g. for point to point radio links, a base station or access point for multiple users (wherein the beam can be steered to each user sequentially or multiple beams can be generated at the same time, interferers can be cancelled out by steering a null to their direction), or a sensor network for communication among the individual devices. Still further, the invention can be used in devices and systems for location and tracking, in which case multiple plasmonic antennas (at least two of them) should be employed at different positions in a room; the target position can then be determined by a cross bearing; the target can be an active or passive RFID tag). The proposed control circuit can be used to drive any electrical structure, which is arranged as an array, such as e.g. pixels of an LCD display, LEDs, light bulbs, elements of a sensor array (photo diodes).

Obviously, numerous modifications and variations of the present disclosure are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single element or other unit may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

The invention claimed is:

1. An optically controlled microwave antenna comprising:

an antenna array comprising a plurality of antenna elements, each said antenna element including:

a waveguide to guide microwave radiation at an operating frequency between a first open end portion and a second end portion arranged opposite the first end portion, said second end portion having a light transmissive portion formed in at least a part of the second end portion,

two optically controllable semiconductor elements arranged within said waveguide, in front of the light transmissive portion of the second end portion, each said optically controllable semiconductor element being configured to change its material properties under control of incident light, the material properties including reflectivity of microwave radiation at the operating frequency,

a controllable light source arranged at or adjacent to the light transmissive portion of the second end portion to project a controlled light beam onto each said optically controllable semiconductor element to control the material properties, and

a septum arranged within said waveguide, in front of the light transmissive portion of the second end portion, and separating said waveguide into two waveguide portions, wherein within each said waveguide portion one of said two optically controllable semiconductor elements is arranged, and

a feed to illuminate said antenna array with and/or to receive microwave radiation at the operating frequency from said antenna array to transmit and/or receive the microwave radiation.

2. The microwave antenna as claimed in claim 1, wherein said waveguide has a quadratic cross section and said septum is arranged to separate said waveguide into said two waveguide portions, each having an identical rectangular cross section.

3. The microwave antenna as claimed in claim 1, wherein said septum has a step profile facing in a direction of the first end portion of said waveguide.

4. The microwave antenna as claimed in claim 3, wherein the step profile has a number of steps in a range of from 3 to 10, or from 4 to 6.

5. The microwave antenna as claimed in claim 1, wherein said feed is configured to illuminate said antenna array with and/or to receive microwave radiation from said antenna array, said microwave radiation having one or two different polarizations, the one or two different polarizations including linear polarizations, circular polarizations, or elliptical polarizations.

6. The microwave antenna as claimed in claim 5, further comprising a feed control unit configured to control said feed to illuminate said antenna array with and/or to receive microwave radiation having a predetermined polarization from said antenna array.

7. The microwave antenna as claimed in claim 1, wherein said optically controllable semiconductor element is configured to switch the material properties between operation as a conductor and a dielectric causing a phase change of 180° of a reflected microwave signal in said waveguide.

8. The microwave antenna as claimed in claim 1, wherein said optically controllable semiconductor element is formed as a post arranged between, in particular contacting, two opposing sidewalls of said waveguide.

9. The microwave antenna as claimed in claim 8, wherein a width of said optically controllable semiconductor element is in a range of from 5% to 50% or 10% to 30%, of a width of said waveguide.

10. The microwave antenna as claimed in claim 8 or claim 9, wherein each said antenna element further includes a support element configured to carry said optically controllable semiconductor element and that is arranged adjacent to said optically controllable semiconductor element, between said two opposing sidewalls.

11. The microwave antenna as claimed in claim 2, wherein each said waveguide portion has a rectangular cross section with a width in a range from 50% to 90% and a height in a range from 25% to 40%, of the wavelength of the microwave radiation at the operating frequency.

12. The microwave antenna as claimed in claim 1, wherein said optically controllable semiconductor element is arranged at a distance d_1 from the second end portion of said waveguide of substantially a guided quarter wavelength of the microwave radiation at the operating frequency.

13. The microwave antenna as claimed in claim 1, wherein the light transmissive portion of the second end portion of said waveguide takes up a portion of 5% to 75% or of 10% to 50%, of a total end area of the second end portion.

14. The microwave antenna as claimed in claim 1, wherein each said antenna element further includes an antireflection element arranged on one or both sides of said optically controllable semiconductor element and having a thickness of substantially a quarter wavelength of the microwave radiation at the operating frequency.

15. The microwave antenna as claimed in claim 1, wherein each said antenna element further includes an aperture element arranged in front of the first end portion of said waveguide and having an aperture larger than an aperture of the first end portion.

16. The microwave antenna as claimed in claim 1,

wherein each said antenna element further includes a waveguide to microstrip transition and a microstrip line, and

wherein said optically controllable semiconductor element is arranged in the microstrip line.

17. The microwave antenna as claimed in claim 1, wherein said optically controllable semiconductor elements of said antenna array are formed in a grid made of a semiconductor material in which a plurality of holes have been formed, a post of said semiconductor material remaining between two neighboring holes representing at least one of said optically controllable semiconductor elements.

18. The microwave antenna as claimed in claim 17, wherein said waveguides of said antenna array are formed by an array of tubes having two open ends, said array of tubes being coupled to said grid such that an open end of each said tube covers two neighboring holes of said plurality of holes and one of said posts is remaining between said two neighboring holes.

19. The microwave antenna as claimed in claim 1, wherein said controllable light source is formed by a laser diode or a light emitting diode.

20. The microwave antenna as claimed in claim 1, wherein said controllable light sources of said antenna array are arranged in a light source matrix, said light source matrix comprising column and row control lines to individually control said controllable light sources.

21. The microwave antenna as claimed in claim 1, further comprising a control circuit including a control unit per said controllable light source or per a group of said controllable light sources configured to control said controllable light sources of said antenna array, each said control unit having a switchable element coupled in parallel to said controllable light source and a switching element to switch said switchable element on and off under control of a switching element control signal.

22. The microwave antenna as claimed in claim 21,

wherein said switchable element is formed by a thyristor or a triac, and

wherein said switching element is formed by a diode.

23. The microwave antenna as claimed in claim 21,

wherein said controllable light sources of said antenna array are arranged in a light source matrix, and

wherein said control circuit further includes a line switch per column or row of said light source matrix to switch a line current provided to a column or row of said controllable light sources coupled in series on and off under control of a line control signal.

24. The microwave antenna as claimed in claim 1, wherein the light transmissive portion is an opening.

25. The microwave antenna as claimed in claim 1, wherein the light transmissive portion includes an indium tin oxide layer arranged in front of said controllable light source.

26. An antenna array comprising a plurality of antenna elements, each said antenna element including:

a waveguide to guide microwave radiation at an operating frequency between a first open end portion and a second end portion arranged opposite the first end portion, said second end portion having a light transmissive portion formed in at least a part of the second end portion,

two optically controllable semiconductor elements arranged within said waveguide, in front of the light transmissive portion of the second end portion, each said optically controllable semiconductor element being configured to change its material properties under control of incident light, the material properties including reflectivity of microwave radiation at the operating frequency,

a controllable light source arranged at or adjacent to the light transmissive portion of the second end portion to project a controlled light beam onto each said optically controllable semiconductor element to control the material properties, and

a septum arranged within said waveguide, in front of the light transmissive portion of the second end portion, and separating said waveguide into two waveguide portions, wherein within each said waveguide portion one of said two optically controllable semiconductor elements is arranged.

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